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RESEARCH MEMORANDUM

LOW-SPEED STATIC LATERAL STABILITY CHARACTERISTICS
OF A CANARD MODEL HAVING A 60° TRIANGULAR
WING AND HORIZONTAL TAIL

By William R. Bates

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

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**NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS**

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SUMMARY

An investigation of the low-speed, power-off static lateral stability characteristics of a canard model with a triangular wing and horizontal tail has been conducted in the Langley free-flight tunnel. When the angle of attack of the fuselage was greater than 12° and the incidence of the horizontal tail was greater than 15° , the horizontal tail produced a strong sidewash which caused the model to be directionally stable with the vertical tail off. At small angles of yaw a vertical tail located on the fuselage was in the sidewash field of the horizontal tail. In this case, the sidewash caused the vertical tail to become less effective and, at angles of attack above 27° , caused the vertical tail to produce a destabilizing moment. The sidewash field from the horizontal tail did not cause twin vertical tails mounted on the wing to produce a similar destabilizing effect because these vertical tails were outside the sidewash field. When compared at a given lift coefficient in trimmed flight conditions, the directional stability of the canard model with the horizontal tail fixed or tail free was generally higher than that of the model without the horizontal tail over the entire lift range.

INTRODUCTION

The National Advisory Committee for Aeronautics has been making a study of canard configurations for high-speed airplanes. Previous results of some force tests in the Langley free-flight tunnel on a canard model similar to that discussed in reference 1 showed that the forward horizontal tail can cause an increase in the directional stability of an airplane at high angles of attack. Because of this characteristic, it was thought that a forward horizontal tail might be used to improve the low directional stability generally associated with triangular-wing

airplanes at high angles of attack. An investigation of the low-speed, power-off stability and control characteristics of a canard model with a triangular wing has been made, therefore, by means of force tests in the Langley free-flight tunnel. The results of the longitudinal investigation for this model have been presented in reference 2.

The model used in the investigation had a 60° triangular wing and horizontal tail. This model was chosen in order to determine whether a canard arrangement would improve the low directional stability at high angles of attack which the model had exhibited in previous investigations without the horizontal tail. Two vertical-tail arrangements were tested: One, a triangular fin mounted on the fuselage; the other, constant-chord twin fins mounted on the wing.

SYMBOLS

All forces and moments were referred to the stability axes which are defined in figure 1. The symbols and coefficients used in the present paper are:

S	total wing area, square feet
$\bar{c}$	wing mean aerodynamic chord, feet
b	wing span, feet
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
V	airspeed, feet per second
ρ	air density, slugs per cubic foot
α	angle of attack of fuselage center line, degrees
β	angle of sideslip, degrees
ψ	angle of yaw, degrees
i_t	angle of incidence of the horizontal tail with respect to the fuselage center line, degrees
α_t	angle of attack of the horizontal tail, degrees
δ_t	horizontal-tail tab deflection, degrees
C_L	lift coefficient (Lift/qS)

C_n	yawing-moment coefficient (Yawing moment/ qSb)
C_l	rolling-moment coefficient (Rolling moment/ qSb)
C_Y	lateral-force coefficient (Lateral force/ qS)
$C_{n\beta}$	rate of change of yawing-moment coefficient with angle of sideslip in degrees ($\partial C_n / \partial \beta$)
$C_{l\beta}$	rate of change of rolling-moment coefficient with angle of sideslip in degrees ($\partial C_l / \partial \beta$)
$C_{Y\beta}$	rate of change of lateral force coefficient with angle of sideslip in degrees ($\partial C_Y / \partial \beta$)

APPARATUS AND TESTS

A three-view drawing of the model used in the present investigation is presented in figure 2. The physical characteristics of the model are given in table I. Two horizontal tails having an area of 8 percent and 16 percent of the area of the wing were used in the investigation. The results obtained with the flat-plate airfoil sections used on the model are approximately the same as would have been obtained with a conventional section, because the aerodynamic characteristics of untwisted delta wings are virtually independent of the airfoil section at low scale. This characteristic has been established by comparison of the aerodynamic characteristics of some flat-plate delta wings from reference 3 with some German data on delta wings (reference 4) having NACA 0012 airfoil sections and with the results of some NACA tests on a 60° delta wing with an NACA 0015-64 airfoil section.

A survey of the flow around the model was made with streamers of string attached to the fuselage and horizontal tail. Visual observations of these streamers were made to determine the nature of the flow over the model at various angles of attack and angles of yaw.

Force tests to determine the aerodynamic characteristics of the model were made on the six-component balance in the Langley free-flight tunnel. The facilities are described in references 5 and 6. All the force tests were made at a dynamic pressure of 3.0 pounds per square foot which corresponds to a Reynolds number of approximately 483,000 based on the wing mean aerodynamic chord.

Tests were made to determine the static lateral stability and control characteristics of the model with the horizontal tail fixed at various angles of incidence and floating freely at various tab

deflections. The lateral stability characteristics were determined in two ways. A general impression of the variation of the lateral stability characteristics with angle of attack was obtained by determining the static lateral-stability derivatives from the difference between the force and moment coefficients measured in tests at 5° and -5° yaw. The lateral stability coefficients were also determined from tests over a range of yaw angles from 20° to -20° for various angles of attack. For the case for which the variation of lateral coefficients with angle of yaw are nonlinear, the plots of lateral coefficients against angle of yaw give a better indication of the lateral stability of the model than the plots of the lateral-stability derivatives against angle of attack.

RESULTS AND DISCUSSION

The results of the preliminary flow survey showed that the flow around the model was normal at low angles of attack, but that at high angles of attack ($\alpha > 12^\circ$) with 15° or 20° tail incidence, the sidewash from the horizontal tail caused an effective reversal of the angle of sideslip of the fuselage, that is, when the model sideslipped to the right the fuselage was effectively in a left sideslip.

The effects of this change in flow are illustrated clearly in figure 3 which presents the results of tests made to determine the directional stability of the model and of various combinations of its component parts. The configurations were identified by the following letters: W for wing, F for fuselage, and so forth. These letters are used in combinations to indicate combined arrangements of various parts. These data show that, although the horizontal tail alone or the wing-fuselage alone were unstable at all angles of attack, the wing-fuselage-horizontal tail combination was directionally stable at angles of attack above 12° and was very stable at high angles of attack. With the horizontal tail off, the vertical-tail effectiveness decreased at the high angles of attack, but the vertical tail produced stabilizing moments even at the highest angles of attack. (See configurations WF and WFFV₁.) With the horizontal tail on, however, the vertical tail became ineffective at 27° angle of attack and actually produced destabilizing moments at higher angles of attack. (See configurations WFH and WFHV₁.) These results indicate that at the highest angles of attack there is a decrease in the vertical-tail effectiveness produced by the interference from the wing-fuselage combination and that a further reduction in effectiveness which causes the vertical tail to become destabilizing is apparently produced by the sidewash from the horizontal tail. The data of reference 7 show that with the horizontal tail off the effectiveness of twin vertical tails also decreases with increase in angle of attack although, with the horizontal tail on, the twin vertical tails were stabilizing at all angles of attack. (See configurations WFH and WFHV₂.) The difference in the effectiveness of the two vertical-tail arrangements (WFHV₁ and WFHV₂)

at high angles of attack is apparently caused by the sidewash from the horizontal tail which passes over the center tail at high angles of attack but does not extend out far enough to materially affect the twin tails at the small angles of yaw (5° and -5°) for which these data were obtained. The difference in the directional stability contributed by the center and twin tails at 0° angle of attack is caused by differences in size and tail length.

Horizontal Tail Fixed

The lateral stability characteristics of the model with the 8-percent and 16-percent horizontal tails fixed at various angles of incidence are presented in figures 4 and 5, respectively. Some of the curves of figures 4 and 5 are repeated in figure 6 to show the effect of tail size on the directional stability of the model. Comparison of the data for the 8-percent and 16-percent horizontal tails at a given lift coefficient shows that increasing the area of the horizontal tail did not have any appreciable effect on the static lateral stability characteristics of the model between angles of yaw of 5° and -5° . It appears from these results that the sidewash field from the 8-percent tail probably covers the fuselage at angles of yaw of 5° and -5° , since increasing the extent of the sidewash field by increasing the size of the horizontal tail had little effect on the lateral stability of the model.

The data of figure 5 show that the lateral-stability derivatives of the model vary considerably with tail incidence so that the static lateral stability of the model in trimmed flight conditions cannot be readily determined from the data presented in figure 5. Figure 7 was prepared, therefore, to show the lateral stability characteristics of the canard model in trimmed conditions with the horizontal tail fixed for two center-of-gravity positions. One center-of-gravity position was the farthest rearward center-of-gravity location at which the model was at least neutrally stable longitudinally over the entire lift-coefficient range with neutral controls. The other was the most forward center-of-gravity location at which the model would trim to the maximum lift coefficient of the model without the horizontal tail ($C_L = 1.0$). These curves were obtained by interpolation from the lateral data of figure 5 and the longitudinal data of reference 2. For comparison, the lateral stability characteristics of the tailless model are presented for two center-of-gravity positions which correspond to that required for neutral static longitudinal stability and that required to give the model about 10-percent static margin. The values of the lateral-stability derivatives for the tailless airplane when trimmed with its center of gravity in the more forward location were obtained from unpublished test results of this model and the values for the rearward center-of-gravity location were obtained from the present investigation.

Figure 7 shows that, when compared at a given lift coefficient, the directional stability of the canard model with the horizontal tail fixed was higher than that of the tailless model for either center-of-gravity location. The difference at low lift coefficients is caused by the difference in length of the tail arm of the vertical tail on the canard and tailless model which results from the center of gravity of the canard model being more forward than that of the tailless model. The additional difference at high lift coefficients is partly caused by the favorable effect of the horizontal tail on the directional stability of the canard model when the tail incidence is high, and partly caused by the fact that the angle of attack corresponding to a given lift coefficient is lower for the canard than for the tailless model. Figure 7 also shows that the effective dihedral of the canard model is generally slightly higher than that of the tailless model and that the lateral force of the canard model is lower than that of the tailless model. In fact, the variation of the lateral force with sideslip is unstable for the canard model at high lift coefficients.

A comparison of the static-lateral-stability derivatives for the model with the single and twin vertical tails is presented in figure 8. This figure presents the derivatives $-C_{Y\beta}$ and $-C_{L\beta}$ as well as the derivative $C_{n\beta}$ which was previously given in figure 3 for the same configurations. In order to obtain a more exact picture of the effectiveness of the vertical tails, the lateral stability coefficients over a range of angles of yaw from 20° to -20° are shown in figure 9. Analysis of these data shows that the twin vertical tails eliminate the nonlinearity associated with the directional stability contributed by the center vertical tail at small angles of yaw. This result indicates that the single vertical tail was in the sidewash field at small angles of yaw.

Horizontal Tail Floating Freely

The lateral stability characteristics of the model with the horizontal tail floating freely at various tab deflections are shown in figure 10. These data show that, when compared at any given lift coefficient, the static lateral stability of the canard model with the tab deflections from 0° to 6.1° was about the same as that of the tailless model. At a tab deflection of 10.5° and moderate angles of attack there was a slight effect of the horizontal tail on the lateral stability characteristics, and with a tab deflection of 16.0° there was a considerable effect on the lateral stability characteristics. The lateral stability characteristics of the model with the horizontal tail free were similar to those with the horizontal tail fixed when the angle of incidence of the tails relative to the fuselage were the same. The variation of the effective angle of incidence with angle of attack for various tab

deflections on the free-floating horizontal tail are shown in figure 11. The tail-fixed data of figure 5 show that there was little effect on the stability characteristics when the angle of incidence and the angle of attack were less than about 10° but considerable effect when both the angle of incidence and the angle of attack were greater than this value. The agreement between the tail-fixed and tail-free characteristics is shown by comparison of the data of figures 5 and 10 which shows that no effect of horizontal tail should be expected for tab deflections from 0° to 6.1° , a slight effect at moderate angles of attack for a tab deflection of 10.5° , and considerable effect for a tab deflection of 16.0° . Apparently, at low tab deflections, the loads on the horizontal tail are too small to produce a strong sidewash effect so that the horizontal tail has virtually no effect on the lateral stability of the model.

Since the static lateral stability of the model in trimmed flight conditions cannot be readily determined from the data presented in figure 10, figure 12 was prepared to show the lateral stability characteristics for trimmed conditions. This figure was prepared in the same manner as figure 7 except that the lateral data of figure 10 were used. Figure 12 shows that the directional stability of the canard model with the tail free was generally higher than that of the tailless model when compared at a given lift coefficient for the most forward center-of-gravity positions or for the most rearward center-of-gravity positions. These center-of-gravity positions were determined in the same manner that they were determined for the tail-fixed case. This figure also shows that the effective dihedral and lateral-force characteristics of the canard and tailless models are generally similar.

The static-lateral-stability derivatives for the model with the single and twin vertical tails are presented in figure 13. In order to present a more exact picture of the effectiveness of the vertical tails, the lateral stability coefficients over a range of angles of yaw from 20° to -20° for the vertical-tail arrangements and with a horizontal-tail tab deflection of 10.5° are shown in figure 14. As in the case of the horizontal tail fixed, analysis of these data shows that the twin vertical tails eliminate the nonlinearity associated with the directional stability contributed by the center vertical tail at small angles of yaw.

General Consideration of Dynamic Behavior

Inasmuch as the results of some NACA free-flight-tunnel tests showed that the lateral flight characteristics of the tailless model were fairly good, the general flight behavior of the canard model with the horizontal tail fixed or free should be expected to be good from considerations of the static-stability derivatives C_{n_β} and $-C_{l_\beta}$. The significance of the unstable lateral-force derivative $-C_{Y_\beta}$ on the

behavior of an airplane, however, is not well understood. It should be noted in this connection that the flying-qualities requirements (reference 8) require that variation of the lateral force with angle of sideslip be stable. It should also be pointed out that the sidewash from the horizontal tail, which has a pronounced effect on the lateral stability of the model, results from the large tip vortices from the horizontal tail and may be unsteady enough to cause some unsteadiness in the lateral motions of the canard model.

CONCLUSIONS

The following conclusions were drawn from an investigation in the Langley free-flight tunnel on a canard model to determine static lateral stability characteristics:

1. When the angle of attack of the fuselage was greater than 12° , and the incidence of the horizontal tail was greater than 15° , the horizontal tail produced a strong sidewash which caused the model to be directionally stable with vertical tail off.
2. At small angles of yaw a vertical tail located on the fuselage was in the sidewash field of the horizontal tail. In this case, the sidewash caused the vertical tail to become less effective and, at angles of attack above 27° , caused the vertical tail to produce a destabilizing moment.
3. The sidewash field from the horizontal tail did not cause twin vertical tails mounted on the wing to produce a similar destabilizing effect because these vertical tails were outside the sidewash field.
4. When compared at a given lift coefficient in trimmed flight conditions, the directional stability of the canard model with the horizontal tail fixed or tail free was generally higher than that of the model without the horizontal tail over the entire lift range.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE CANARD MODEL WITH A
TRIANGULAR WING TESTED IN THE LANGLEY FREE-FLIGHT TUNNEL

Wing:

Area, sq ft (total)	2.95
Span, ft	2.61
Aspect ratio	2.31
Mean aerodynamic chord, ft	1.505
Sweepback of leading edge, deg	60
Dihedral (relative to mean thickness line), deg	0
Taper ratio (tip chord/root chord)	0
Airfoil section	Flat plate

Elevon:

Type	Plain
Area (one), sq ft	0.268
Span (at trailing edge of wing, one), ft	1.14
Chord (from hinge line to trailing edge), ft	0.254

Horizontal tail:

Area, sq ft	0.472
Span, ft	1.045
Aspect ratio	2.31
Sweepback of leading edge, deg	60
Tab area, sq ft	0.1062
Tab chord, ft	0.1042
Airfoil section	Flat plate
Distance from c.g. to tail hinge line, ft	1.027

Single vertical tail:

Area, sq ft	0.527
Height, ft	0.78
Aspect ratio	1.155
Sweepback of leading edge, deg	60
Taper ratio (tip chord/root chord)	0
Rudder area, sq ft	0.1055
Rudder chord, ft	0.1425
Airfoil section	Flat plate
Tail length (distance from c.g. to center of area), ft	0.830

Twin vertical tail:

Area, sq ft	0.659
Height, ft	0.639
Aspect ratio	1.24
Sweepback of leading edge, deg	45
Taper ratio (tip chord/root chord)	1.0
Airfoil section	Flat plate
Distance from fuselage center line to vertical tail, ft	0.823
Tail length (distance from c.g. to center of area), ft	1.495

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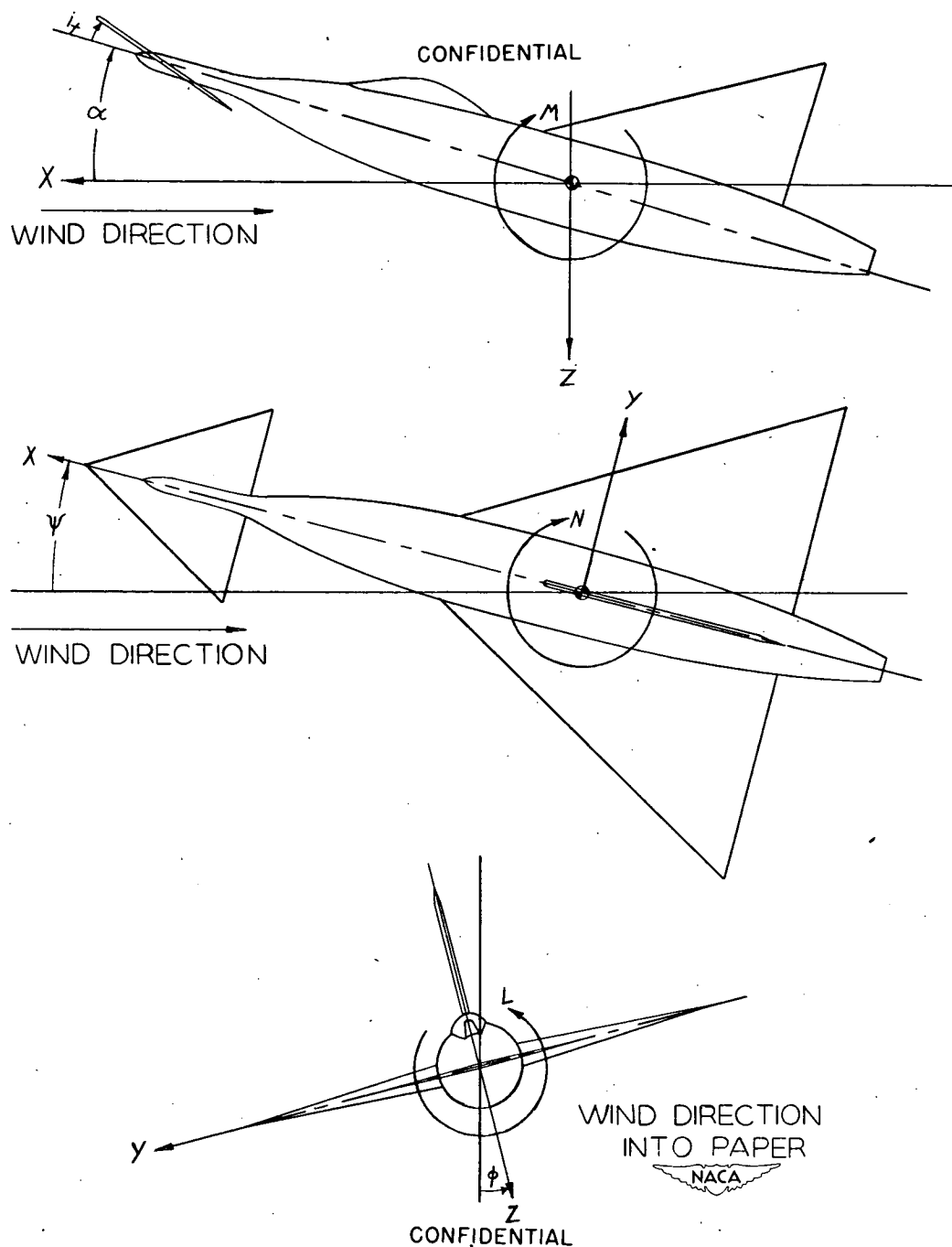


Figure 1.- The stability system of axes. Arrows indicate positive directions of moments, forces, and control-surface deflections. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

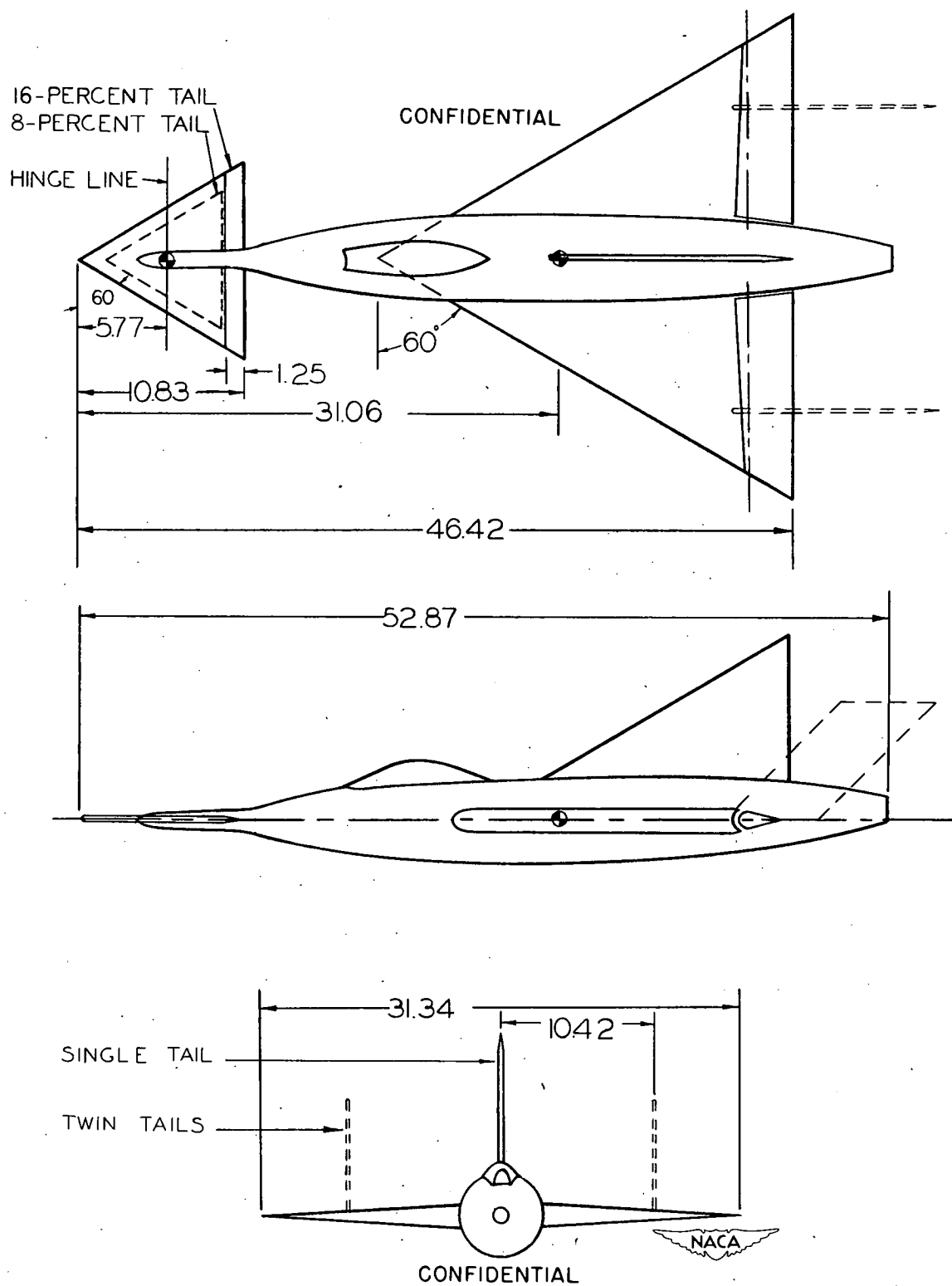


Figure 2.- Three-view drawing of the model showing the various horizontal-tail and vertical-tail configurations.

W wing
F fuselage
H 16-percent horizontal tail, $i_t = 15^\circ$
*V*₁ center vertical tail
*V*₂ twin vertical tails

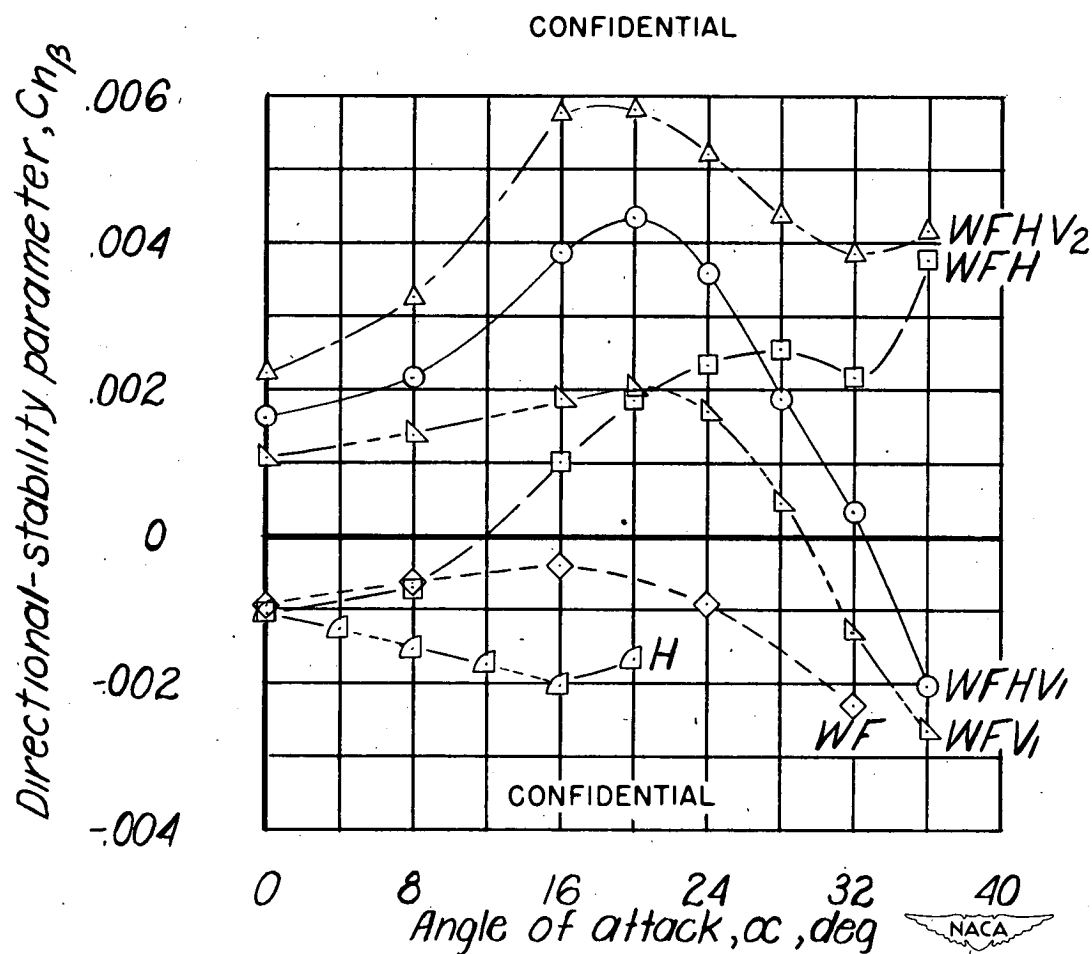


Figure 3.- Directional stability characteristics of various combinations of the component parts of the model.

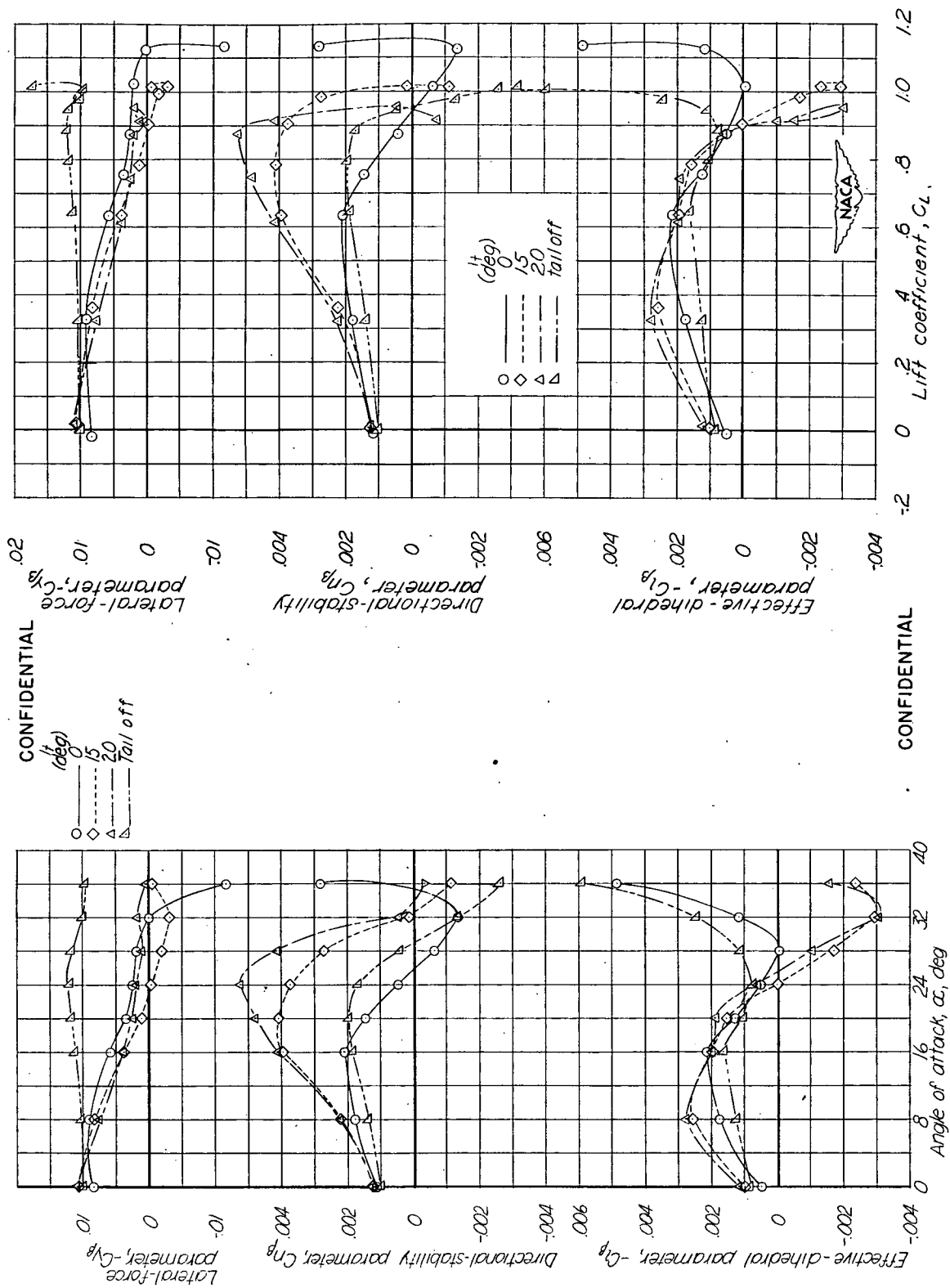


Figure 4.- Lateral stability characteristics of the model with the 8-percent horizontal tail fixed at various angles of incidence. (Center vertical tail)

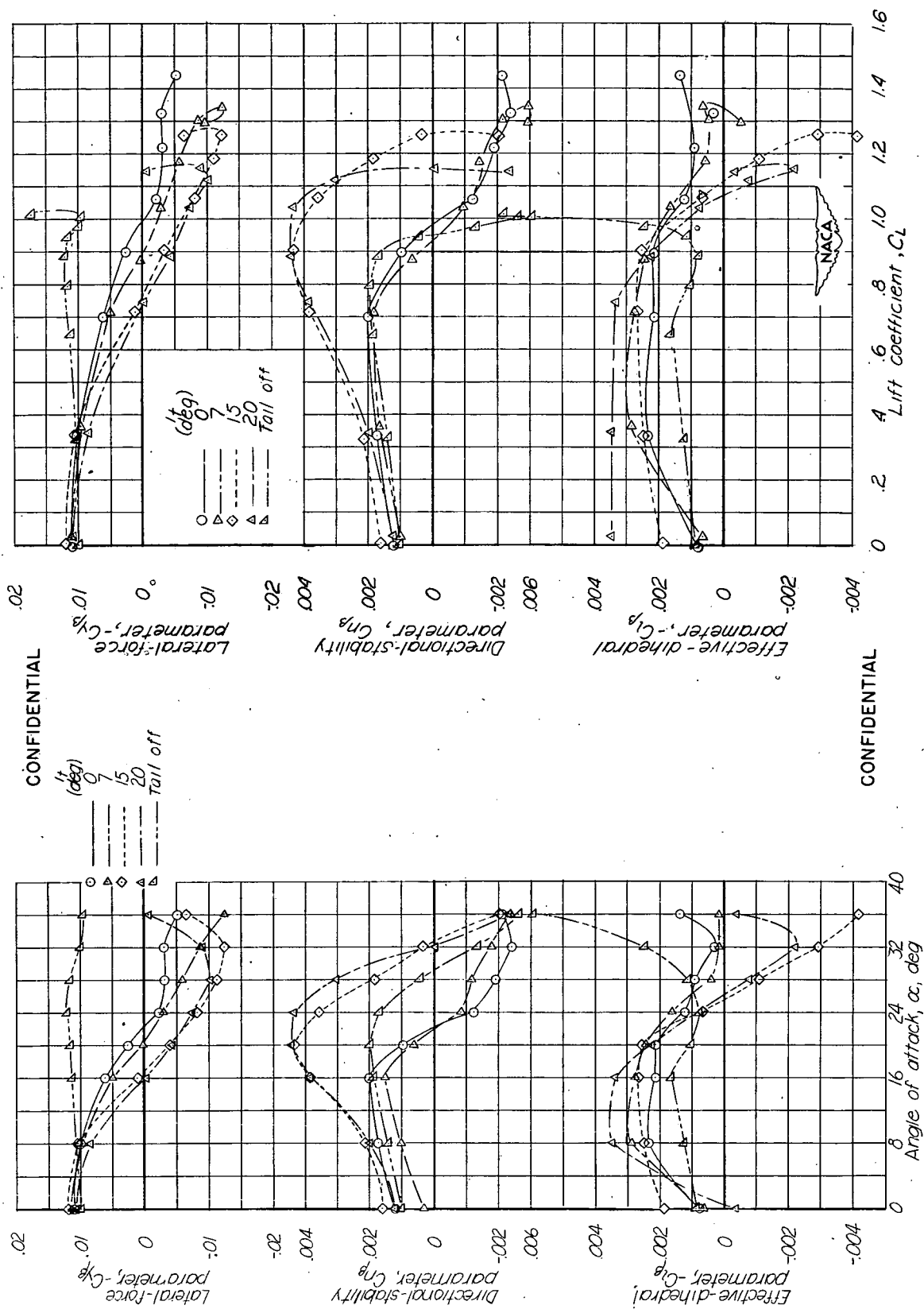


Figure 5.- Lateral stability characteristics of the model with the 16-percent horizontal tail fixed at various angles of incidence. (Center vertical tail)

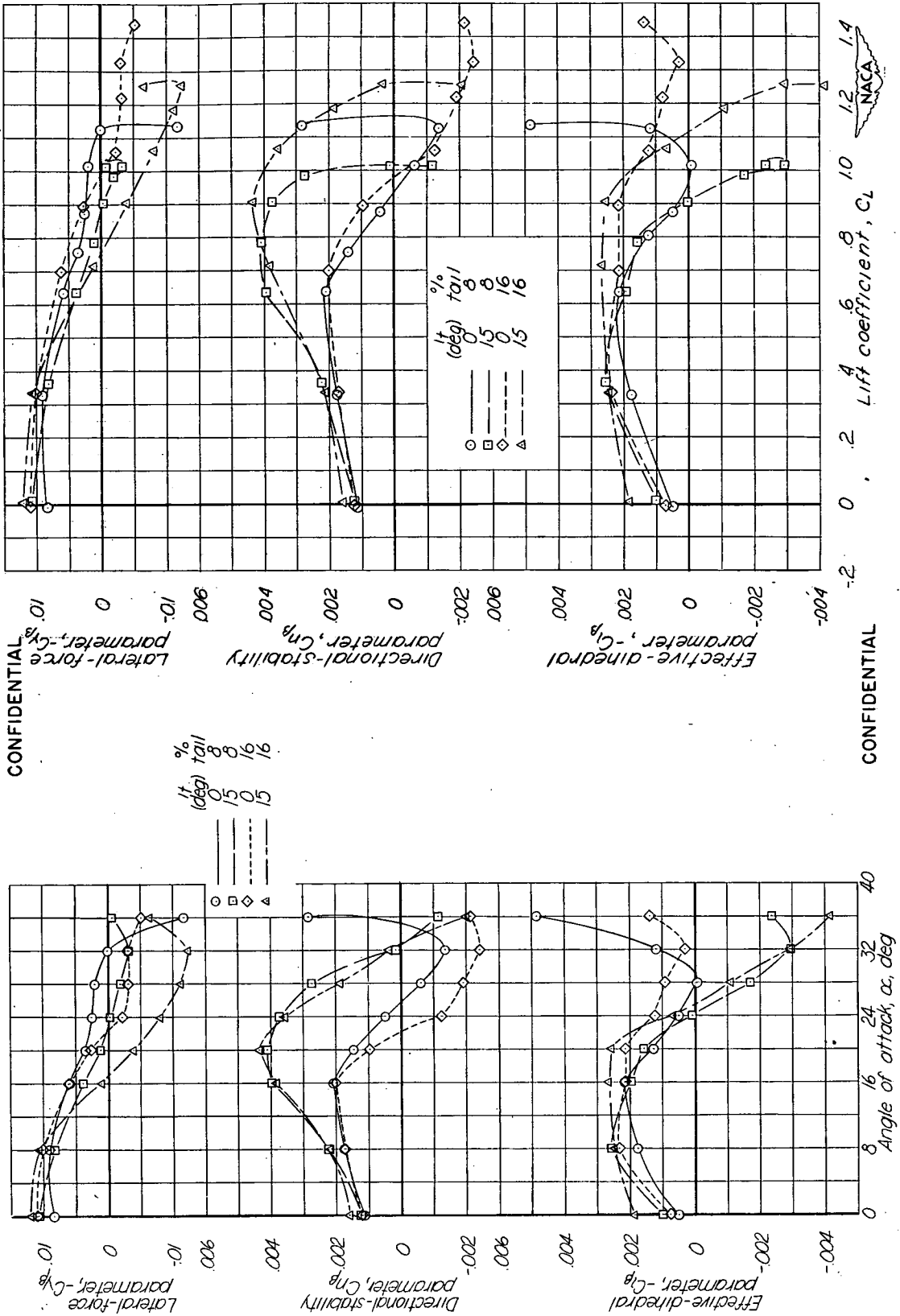


Figure 6.- Effect of horizontal-tail size on the lateral stability characteristics of the model with the horizontal tails fixed. (Center vertical tail)

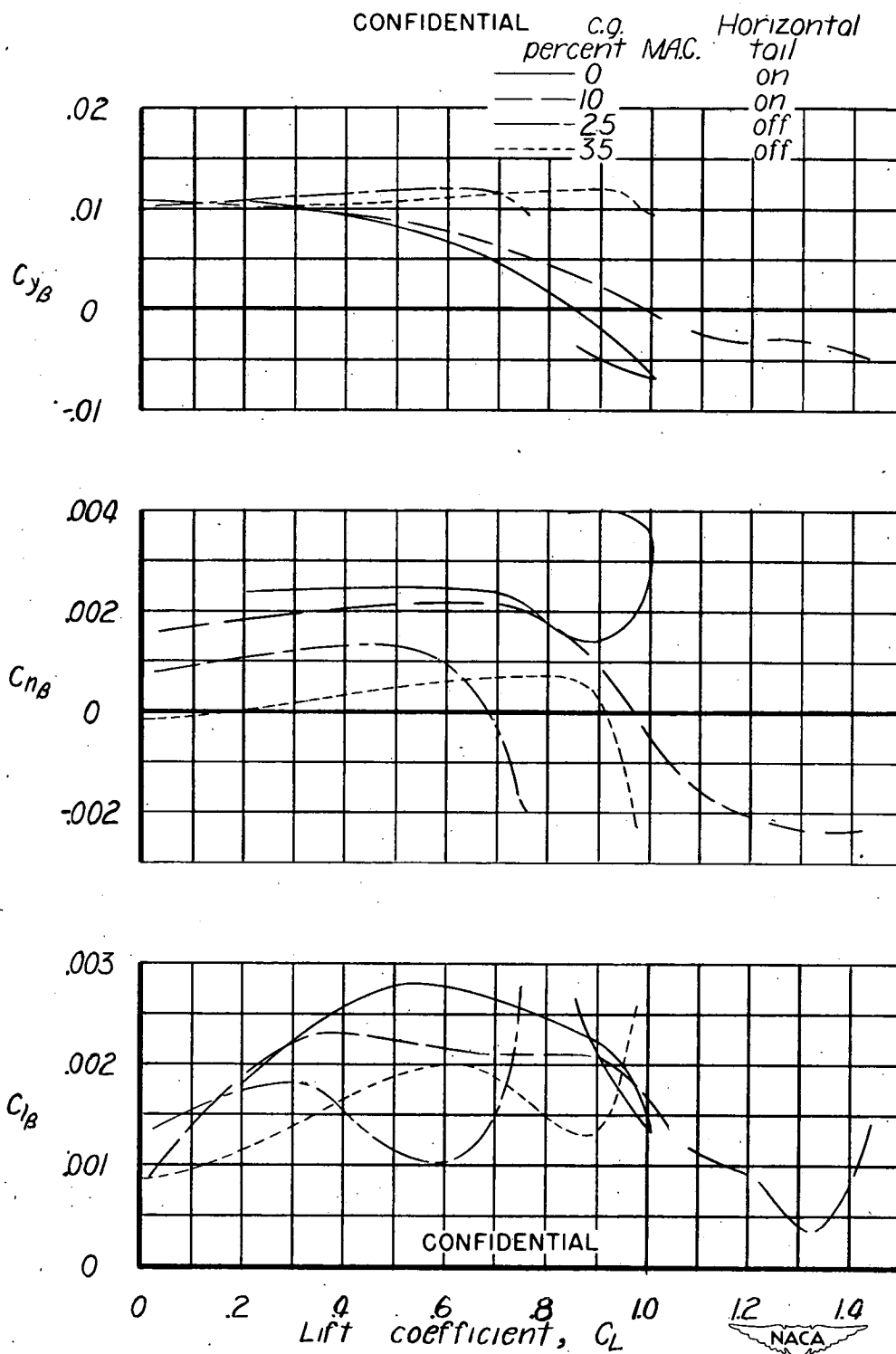


Figure 7.- Comparison of the lateral stability characteristics of the model with and without the 16-percent fixed horizontal tail for trimmed flight conditions. (Center vertical tail)

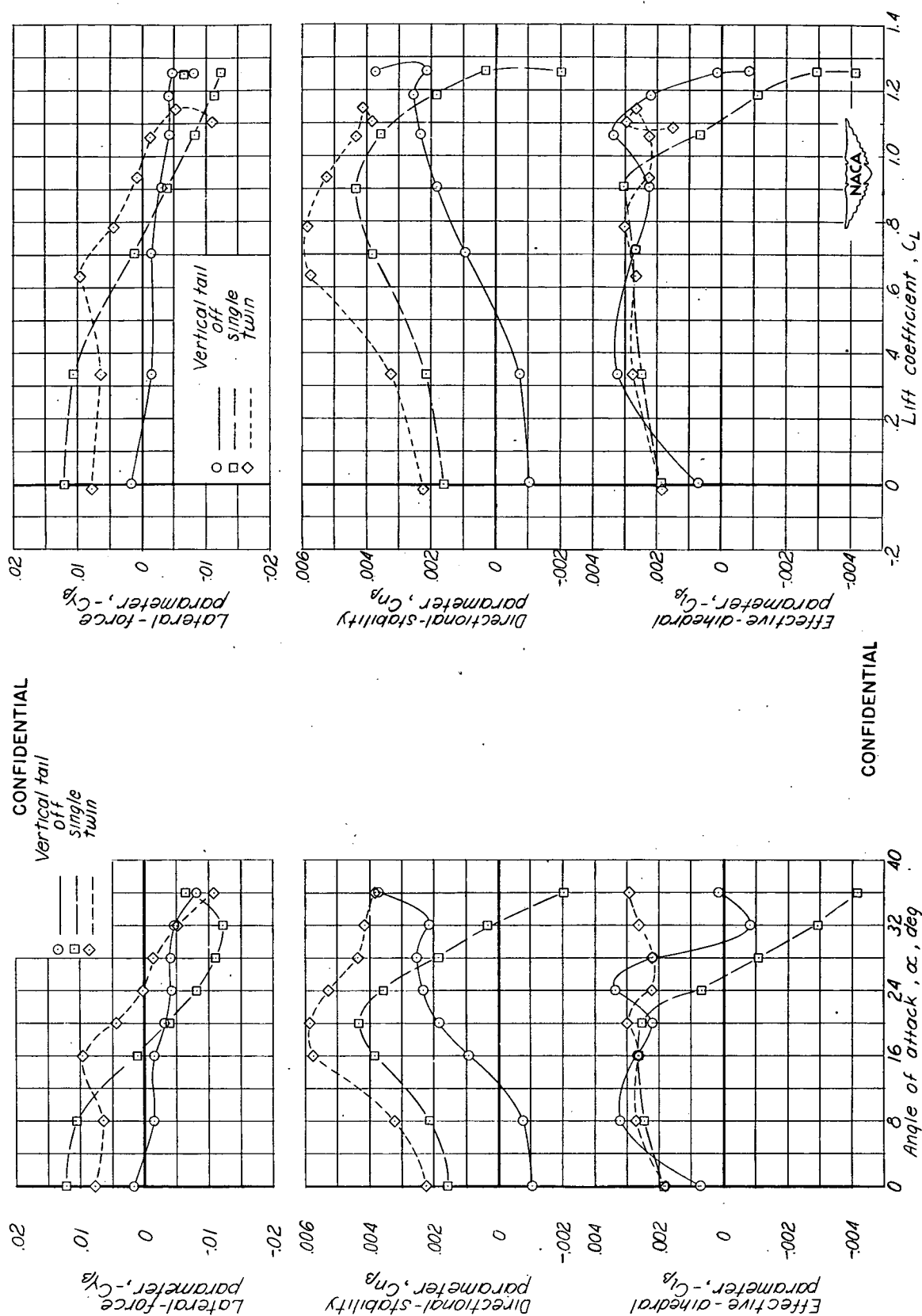


Figure 8.- Lateral stability characteristics of the model with various vertical tail arrangements.
(16-percent horizontal tail fixed at 15° incidence)

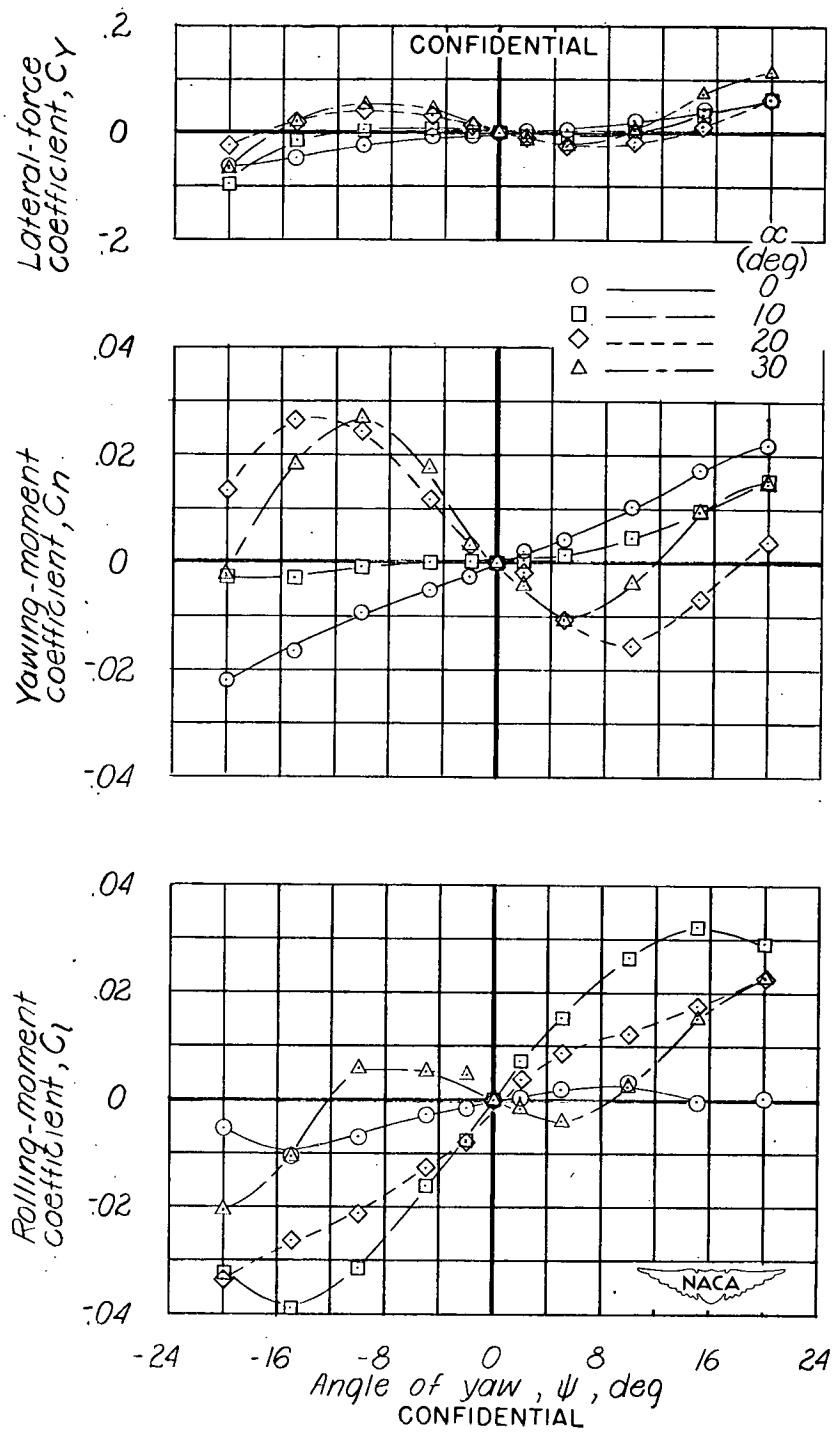
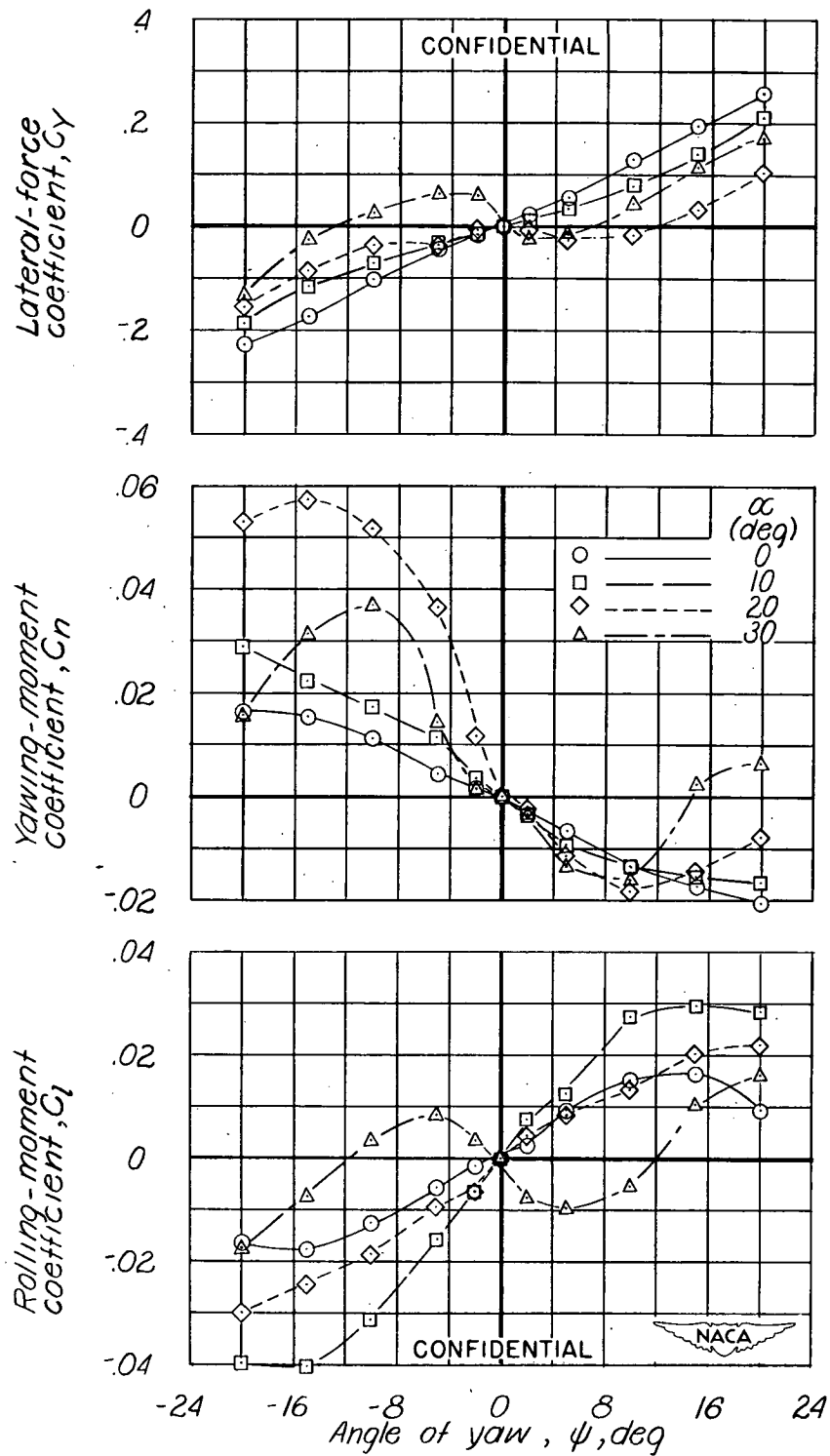
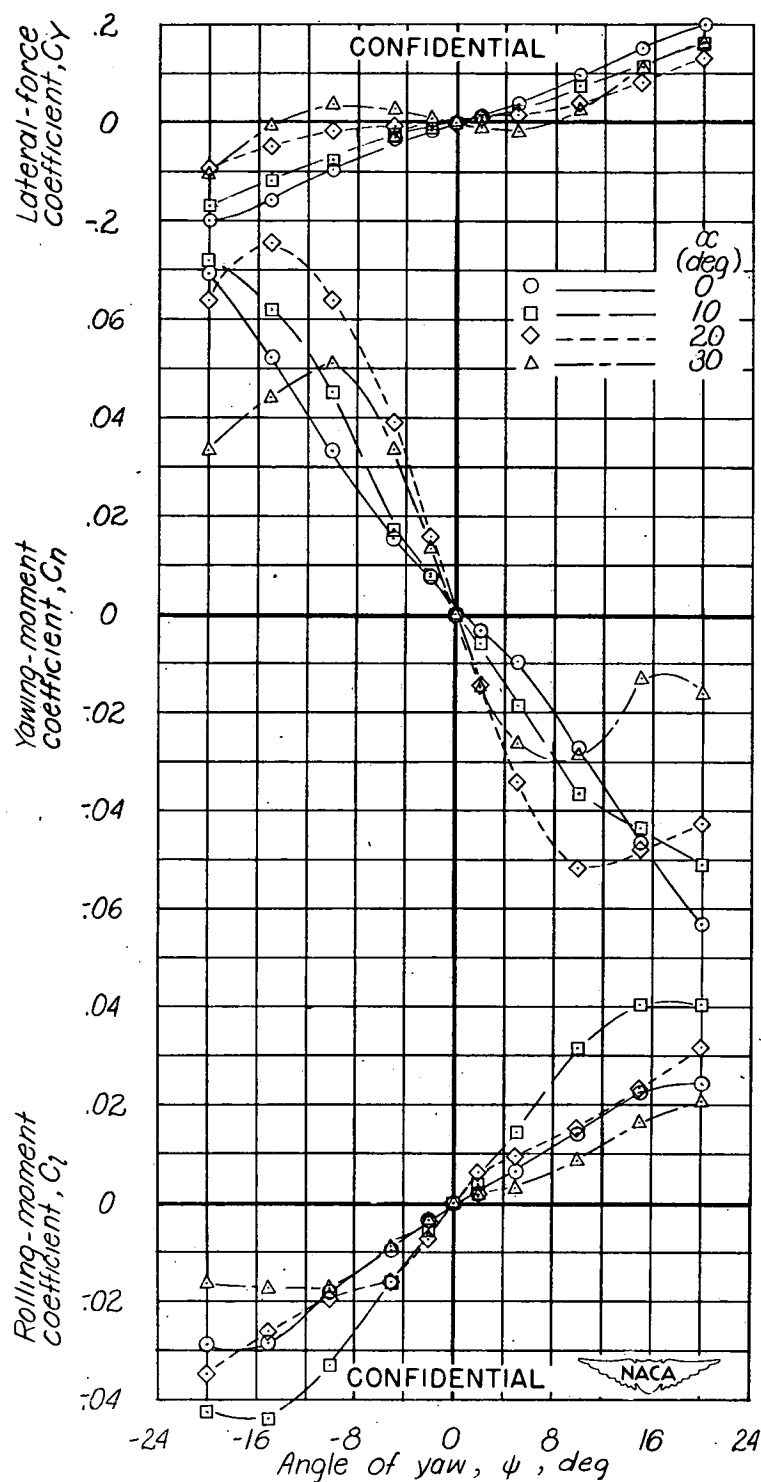


Figure 9.- Effect of angle of attack on the lateral stability coefficients of the model over a range of angles of yaw. (16-percent horizontal tail fixed with $i_t = 15^\circ$)



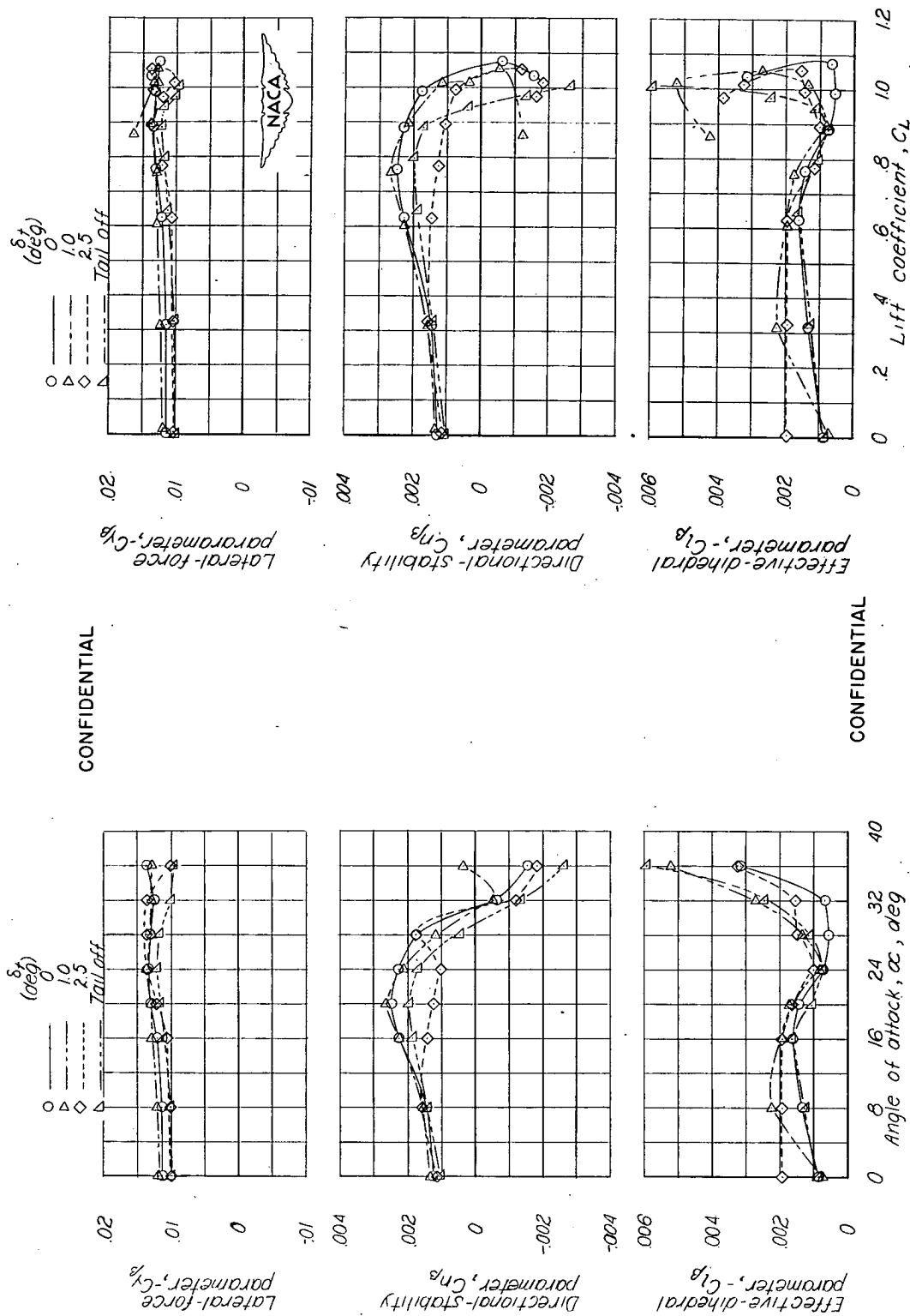
(b) Center vertical tail.

Figure 9.- Continued.



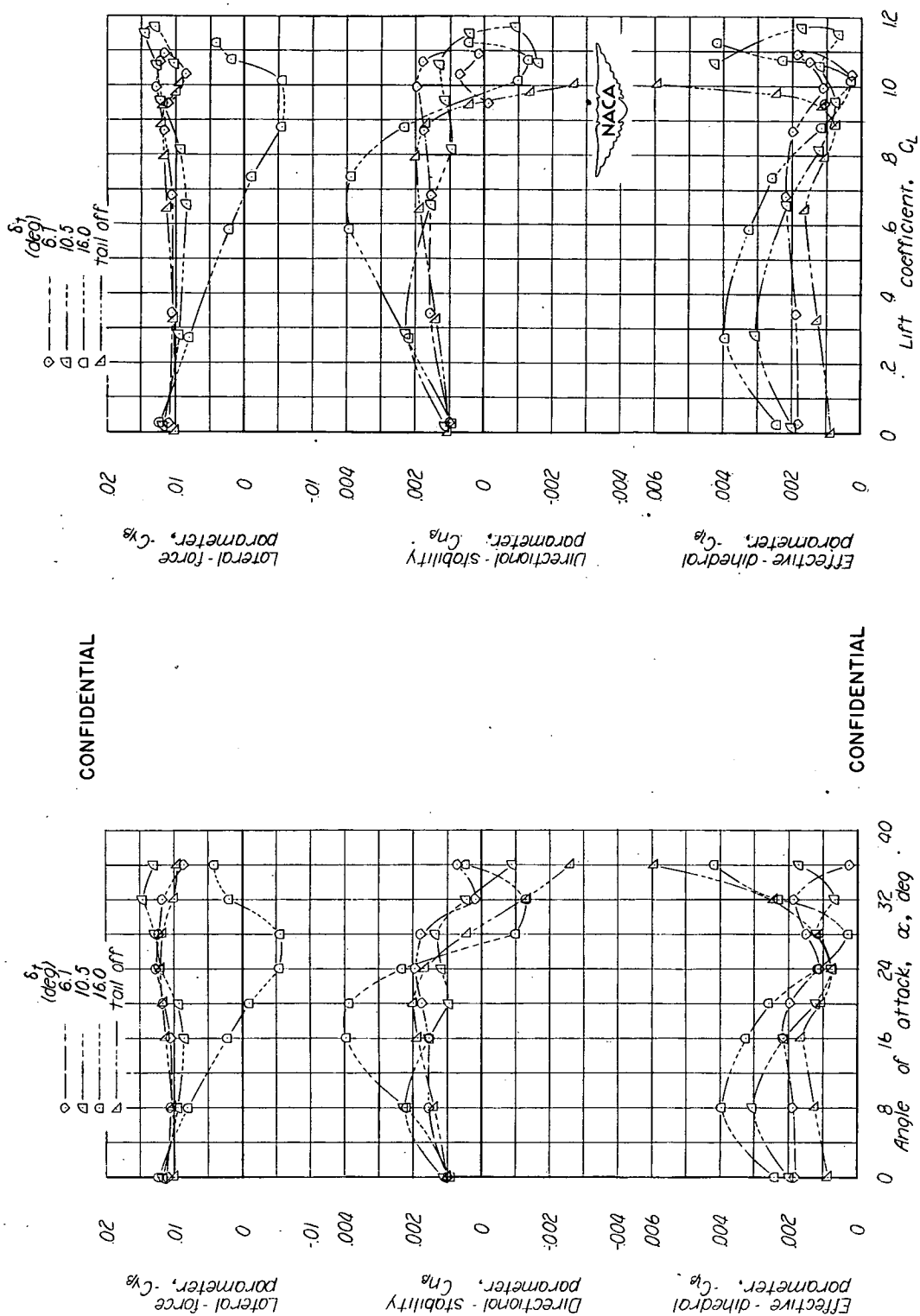
(c) Twin vertical tails.

Figure 9.- Concluded.



(a) $\delta_t = 0^\circ$, 1.0° , and 2.5° .

Figure 10.- Lateral stability characteristics of the model with 16-percent horizontal tail floating freely at various tab deflections. (Center vertical tail)



(b) $\delta_t = 6.1^\circ$, 10.5° , and 16.0° .

Figure 10.- Concluded.

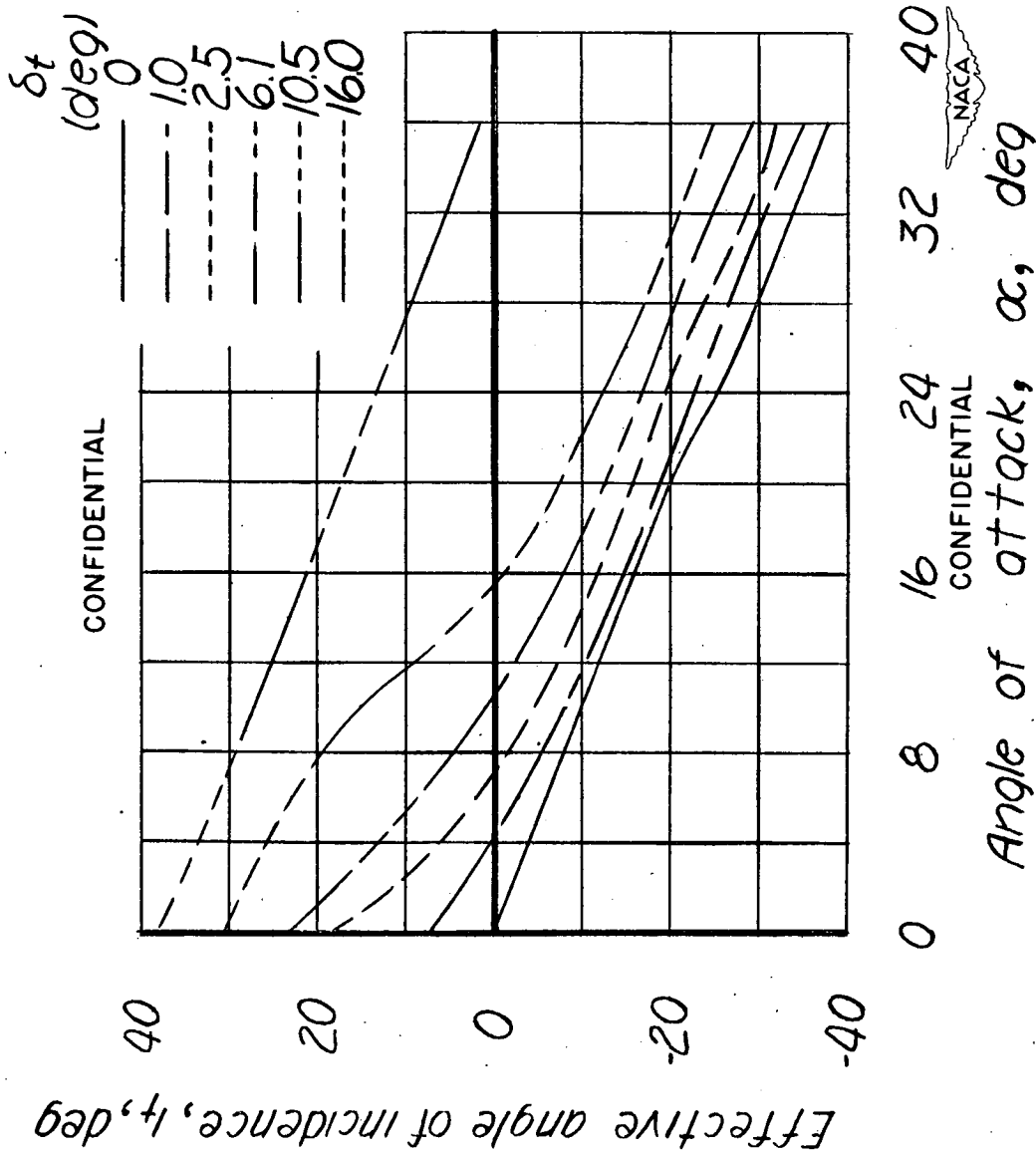


Figure 11.- Variation of the effective angle of incidence with angle of attack for various tab deflections on the free-floating horizontal tail.

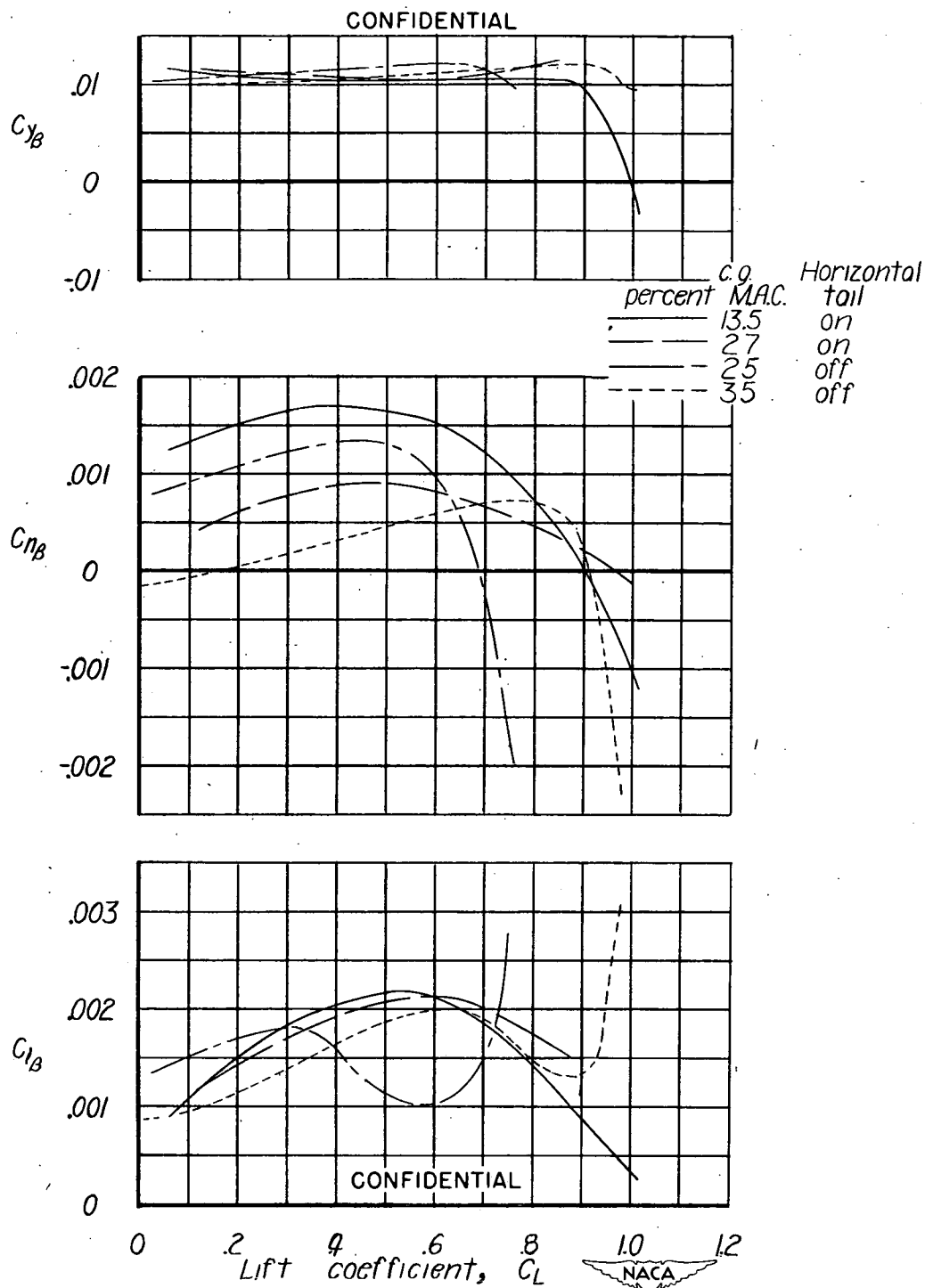


Figure 12.- Comparison of the lateral stability characteristics of the model with and without the 16-percent free-floating horizontal tail for trimmed flight conditions. (Center vertical tail)

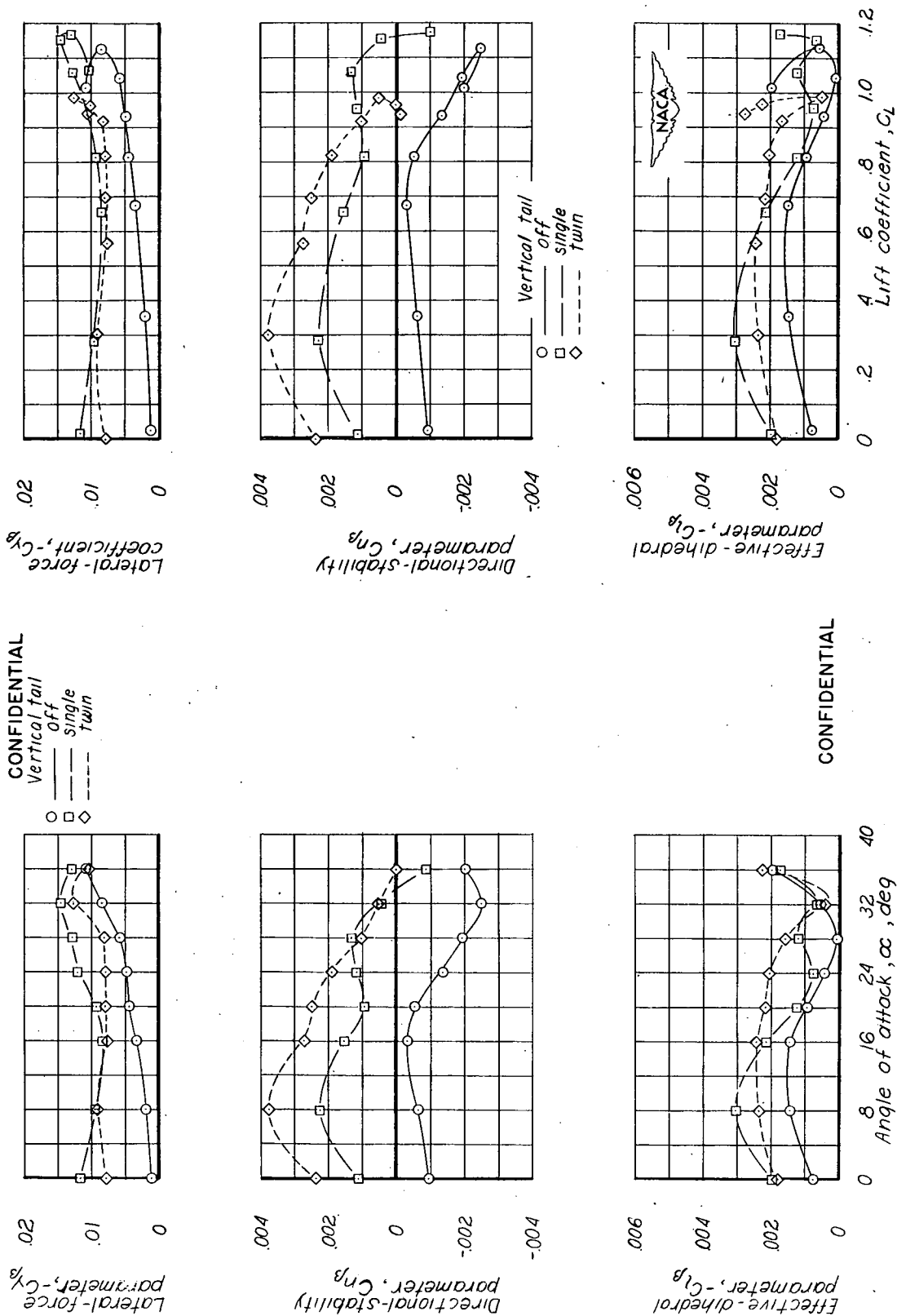
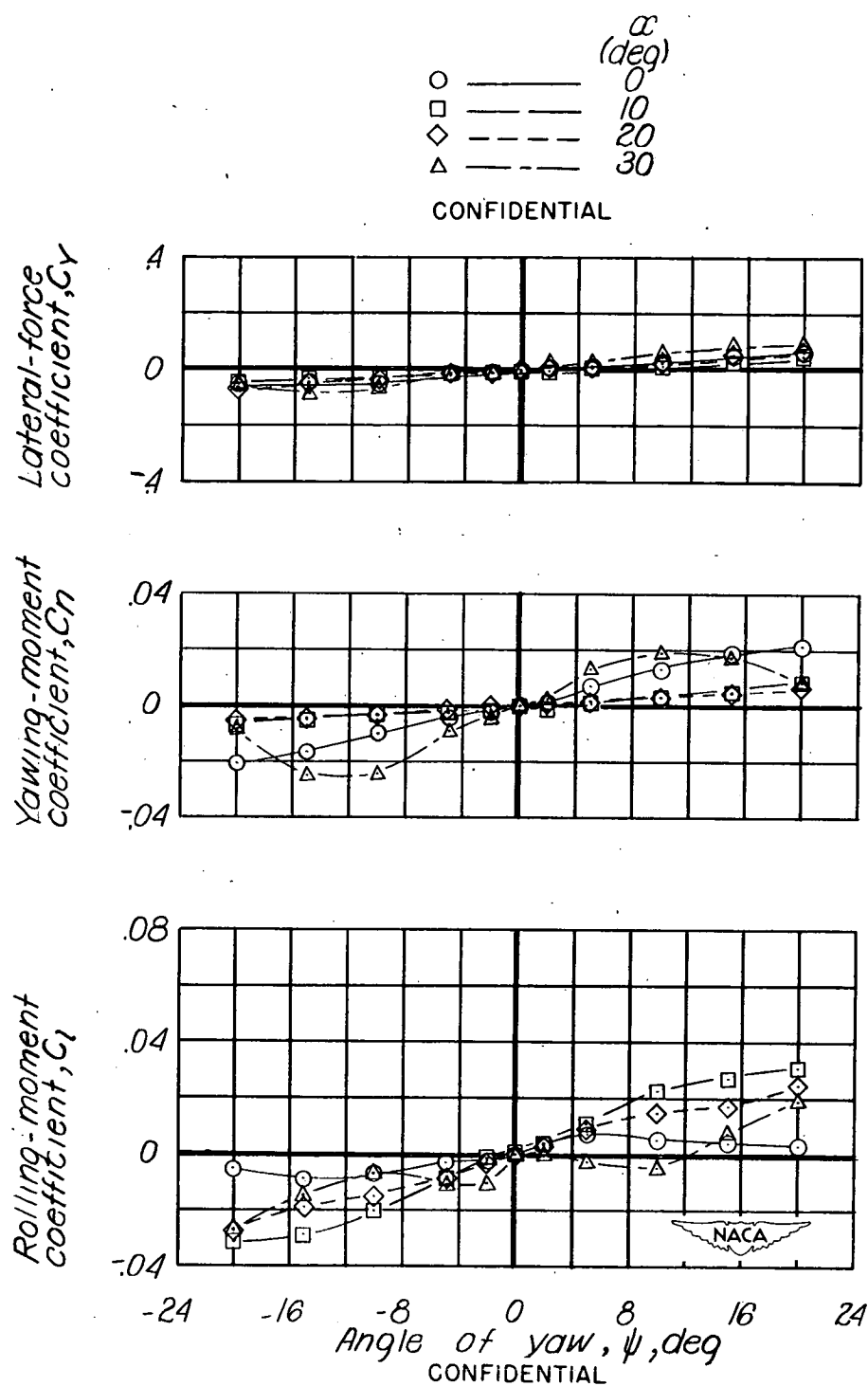


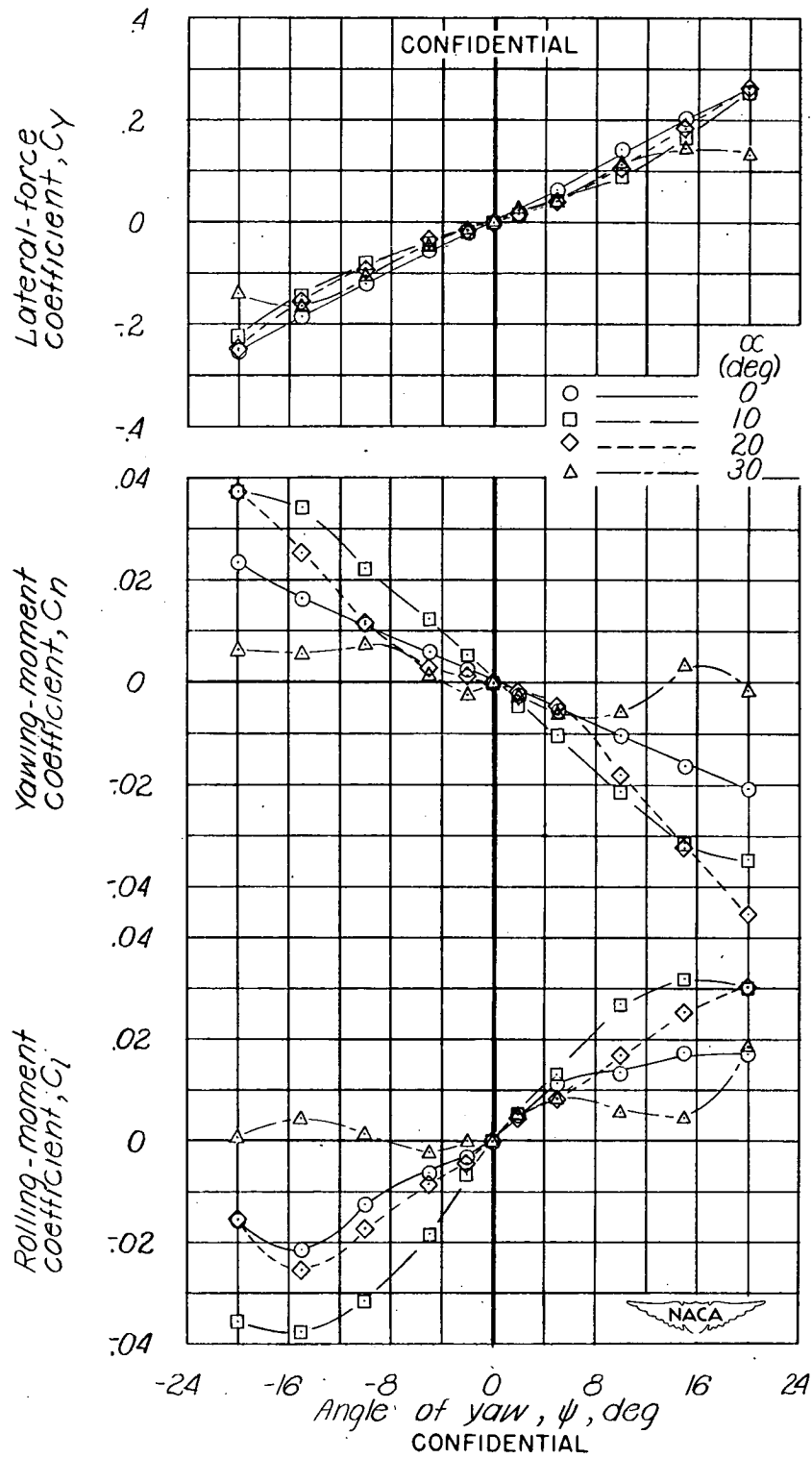
Figure 13.- Lateral stability characteristics of the model with various vertical tail arrangements.
(16-percent horizontal tail floating freely at 10.5° tab deflection)



(a) Vertical tail off.

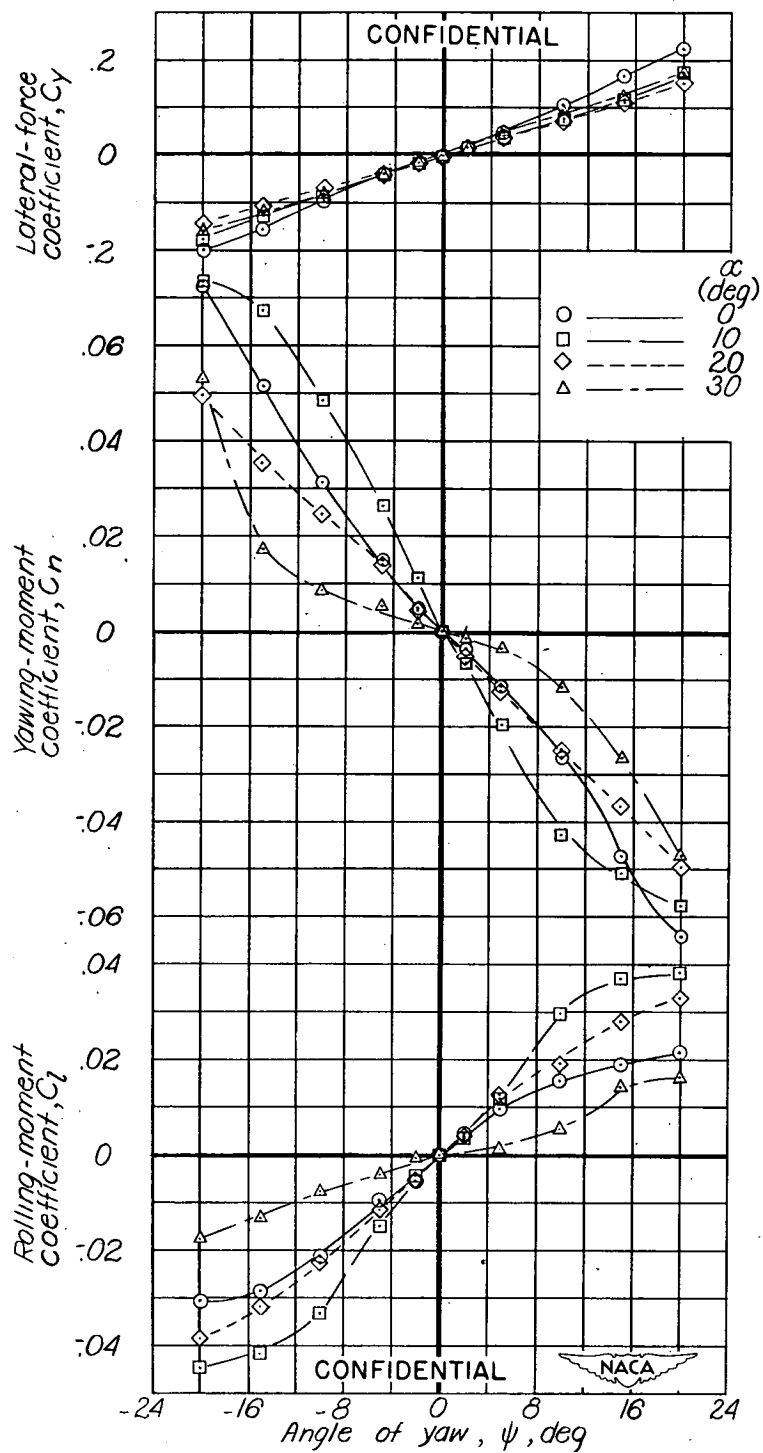
Figure 14.- Effect of angle of attack on the lateral stability coefficients of the model over a range of angles of yaw.

(16-percent horizontal tail floating freely with $\delta_t = 10.5$)



(b) Center vertical tail.

Figure 14.- Continued.



(c) Twin vertical tails.

Figure 14.- Concluded.